PHILOSOPHICAL

TRANSACTIONS.

I. *The Croonian Lecture. Microscopical observations on the suspension of the muscular motions of the Vibrio Tritici.* By FRANCIS BAUER, *Esq. F. R. S. F. L. S. and H. S.*

Read December 5, 1822.

THE Croonian Lecture has usually been given by Members who had made Physiology their particular study; and I should not have ventured upon this task, had I not been encouraged by one of our Vice-Presidents, who has now, for some years, applied my microscopical observations in promoting physiological enquiries into the more minute parts of animal structure.

Without his authority, I should not have ventured to bring forward the following observations, respecting the length of time the moving powers of an animal, too small to become the object of sight without the assistance of the microscope, can have its action suspended, and again, by a change of circumstances, renewed.

This, he is induced to believe, is one of the most curious facts respecting muscular motion that has hitherto been as-

certained, and not undeserving of the notice of the Society, particularly when laid before its members as a part of this Lecture, to which it most peculiarly belongs.

This minute animal, the Vibrio Tritici, is the immediate cause of that destructive disease in wheat, known under the name of Ear Cockle, or Purples, by farmers.

On opening some of the diseased grains, I found their cavities filled with a mass of a white fibrous substance, apparently cemented together by a glutinous substance, and formed into balls, which could easily be extracted entire from the cavities of the grains, and which, when immersed in water, instantly dissolved, and displayed in the field of the microscope, hundreds of perfectly organized, extremely minute worms, all which, in less than a quarter of an hour, were in lively motion.

Having left some of these worms on a glass for five days in a perfectly dry state, they were apparently dead; but when moistened, they were again, in less than half an hour, as lively as ever.

These experiments and results were so far satisfactory, as they incontestibly established the fact, that the fibrous substance within the cavities of the diseased wheat grains, consists of real organized animals, which are endowed with the extraordinary property, of having their muscular action suspended for a considerable length of time, and of having it renewed again by the mere application of moisture: but how these animals are propagated, and how they are introduced into the cavities of the young germens, appeared to me a mystery, which I was convinced could only be unravelled by tracing them through every stage of the germination and

vegetation of the growing plant of wheat; and believing that the eggs of these worms must be conveyed into the cavities of the very young germens of the flowers of wheat by the circulating sap, in the same manner as the seed of the parasitical fungi which occasion the well-known disease in wheat, the smut-balls, and which I had, in former experiments, successfully inoculated upon sound wheat, I determined to try the same experiment with these worms. I therefore selected some sound grains of wheat, and placed some portions of the mass of worms in the grooves on the posterior sides of the grains, and planted them in the ground in the month of October, 1807. Nearly all the seeds came soon up, and I took from time to time some of the young plants for examination, but could not perceive any effect of the inoculation, till the month of March, 1808, when, in carefully slitting open the short stalk of a young plant, I found three or four worms within it; they were in every respect the same, but they were now about two-thirds larger, as well in length as in diameter.

On the 5th of June I found, for the first time, some of the worms, of different sizes, within the cavities of the young germens; and having, in the beginning of March, found some of them in an enlarged state in the stalk, I concluded that some of the original worms, with which I had inoculated the grains of seed, had got, during the germination of the grains, into the stalk, where they became mature, and laid their numerous eggs, some of which must be carried by the circulating sap into the cavities of the then forming young germens, in which the young worms extricate themselves from these eggs; and finding their proper nourishment

within the cavities of the germens, these young worms become of mature age, and lay their eggs within the cavities of these germens, which at that period nearly approach towards maturity; and these newly laid eggs, I consider to be the beginning of the third generation of the worms with which I had inoculated the grains planted in the ground in October, 1807.

Since the 5th of June, I regularly examined every second or third day an ear, to observe the progressive advancement, as well of the worms as of the germens; towards the end of June, the germens assumed various distorted forms, and began to be filled with eggs. I extracted carefully the whole contents of one of the largest grains, and putting it into water in a watch-glass, I found, on examination under the microscope, seven large worms, a great many eggs, and at least a hundred young worms, all alive, bending and twisting in the water like so many small serpents.

The natural size of the largest of these seven worms I found, by means of the micrometer, to be something more than $\frac{1}{4}$ part of an inch in length, and about $\frac{1}{80}$ part of an inch in diameter. They are more of a yellowish-white colour than the young worms, and are not so transparent; their heads are very distinct; they have a kind of proboscis, which has three or four joints, which they contract or extend like an opera glass. From the head, which is somewhat roundish, they taper gradually off towards the tail, which is scarcely half the diameter of the middle of their body, and ends in an obtuse claw-like point. At a short distance from the end of the tail is an orifice, surrounded by an elevated fleshy edge; from this orifice the worms discharge their eggs. The back

of these old worms is nearly opaque, and appears jointed, or annular; the number of joints, or rings, is from twenty-five to thirty; the belly side is more transparent; and strings of ova can be distinctly seen, through almost the whole length of the worm, to the orifice by which the eggs are discharged.

The movements of these large worms are very faint and slow; they are very seldom observed to unroll themselves entirely; they move their heads and tails faintly, but their proboscis they move constantly, extending and contracting it quickly; and when in the act of discharging their eggs, they bend the tailpiece upwards with a very quick jerk, at the passing of every egg; after having discharged all their eggs, the parent worms soon die, and in a few days they decay, and fall to pieces almost at every joint.

The eggs come out from the orifice in strings of five or six, adhering to one another at their ends, which then appear truncated; but, in water, they soon separate, and assume an oval form, which, in its middle, is slightly contracted. These eggs consist of an extremely thin and transparent membrane, through which the young worm can be distinctly seen; and, if attentively observed, it may be seen moving within this envelope. The egg is about $\frac{1}{300}$ part of an inch in length, and $\frac{1}{800}$ or $\frac{1}{900}$ part of an inch in diameter.

In about an hour and a half after the egg is laid in water, the young worm begins to extricate itself from the egg. One extremity of the worm (which I consider to be the head) comes out at one end of the egg; and by continual twisting and active exertion, the young worm comes gradually entirely out. I watched one individual from the first appearance of its head till it was entirely extricated, the operation was

effected in one hour and twelve minutes. The eggs, after the worms have quitted them, soon shrivel and decay, and it seems they ultimately dissolve, as in a very few days they entirely disappear, as well those in the water, as those that have been hatched within the germens.

The young worms are somewhat smaller and more transparent than those which are found in the more mature grains, but in a very short time after they have mixed with the others, they cannot be distinguished from them. Those which are found in the cavities of the mature grains, are nearly all of the same size; they are from $\frac{1}{33}$ to $\frac{1}{36}$ part of an inch in length, and $\frac{1}{1200}$ part of an inch in diameter. They are milk-white, semi-transparent; and if viewed with the strongest magnifying power, appear annular, like the large worms, though no external indentations are observable; they appear like fine glass tubes filled with water, and containing many air bubbles in close succession, and of the same number as the rings or joints in the old worms. At both extremities (one of which is more sharply pointed than the other), there are no such divisions or joints perceptible. These extremities are each about $\frac{1}{6}$ of the whole length of the worm; they are perfectly transparent, and appear like solid glass.

Respecting the sex of these minute animals, I could never discover any external distinction. The old worms in the same germen are almost every one of a different size; they have all the same proboscis and the same orifices. Three of the seven worms from the same grain which I first examined, were laying their eggs at the same time, though they were not of precisely the same size; but the other four did not; they were considerably smaller, and evidently much

younger; but I have not the least doubt, had they been left undisturbed in the grain, they would, at the proper period, have attained the same size as the others, and would have produced eggs.

This opinion I consider confirmed by my subsequent investigations of grains approaching nearer to maturity; in them there was no such striking difference in size; at that period, the old worms in the same grains, which probably laid their eggs first, were now in a decaying state; some parent worms were found dead, and those still alive were laying eggs, and of the same size as those which I had before observed in the act of discharging their eggs. I also found that the infected germens in the upper part of the ears very frequently contained only one single large worm; notwithstanding which, these germens were gradually filling with eggs, in the same manner as those in which originally there was more than one worm; and among the diseased germens of plants which I had inoculated with the worms and the fungi of the smut-balls, both diseases having taken effect, I found several germens containing only two or three large worms, which formed as many distinct nests within the same germen, having each of them a large distinct cluster of eggs, kept separate by the fungi of the smut-balls that occupied the cavities within those germens.

From all the observations I had an opportunity of making, it appears, that there is no distinction of sex, and that they are true hermaphrodites.

The latter end of July, the diseased grains had almost all attained their full size, and assumed a brownish tint; and about the fifth of August they were all of a dark brown co-

lour, variously distorted, and as hard as wood. The cavities of these grains were now completely filled with young worms, and these worms were, in every respect, the same as those with which I had inoculated my first seed grains; and those specimens were now more than twelve months old, and, consequently, the grains and the worms within them were completely dry; but after soaking them in water about an hour, the worms recovered their powers of moving, and were again as lively as those which were taken from the living plants.

These experiments I repeated with grains from the same specimens, for five years and eight months, always with the same success; but I observed that the longer the grains were kept dry, the longer they required to remain in water before the worms recovered their motion; but after the expiration of five years and eight months the worms were really dead.

The worms of the specimens which were the produce of my inoculated plants, retained their reviviscent quality for six years and one month; and this is the longest time of suspension I have hitherto ascertained; after that time the power of resuscitation ceased.

The large worms, after they become dry, die, and never revive; neither can the young worms within the eggs be revived, if the eggs have been but for a moment dry before the worms have extricated themselves.

Experiments with such worms as had been revived in water before, and had been dried again, I repeated many times; I soon found that those which had been kept the shortest time in water, recovered their motions soonest; so that those which had been examined on the plain object-glass where

only a very small quantity of water can be applied, which very soon evaporates, almost every individual worm recovered in less than a quarter of an hour; and if the water is a second time suffered soon to evaporate, the experiment may be repeated many times successfully with the same worms; but after the second or third repetition, if there is a suspension of a week or ten days at each interval, several worms do not revive, and the number of these increases at every succeeding repetition. If this experiment be not repeated too soon or too frequently, the worms retain their reviviscent quality much longer; the longest period of recovery, after a second suspension, I have hitherto ascertained, was eight months.

If the worms are kept alive in water for a week or ten days, the experiment cannot be repeated so often, but the intervals of suspension may be prolonged considerably. I made the experiment very recently with grains which were three years and ten days old, and dry. After extracting the worms from the grains, I kept them in water thirty-five days, and after they had again been fifteen days perfectly dry, I supplied them with water, and in less than twelve hours soaking they were again, almost every individual, in as lively motion as if they had just been taken from fresh grains of the growing plant. I had the pleasure of showing these worms, in that state, to several Members of the Society, on the 29th of September last; after that day, I preserved the same specimens eighteen days, perfectly dry; when, supplying them with water, I found, in less than three hours, at least one-third of them in lively motion; but the next morning,

after they had just been sixteen hours in water, they were all dead.

If these worms are kept in a large glass, where the water cannot evaporate, they remain alive more than three months, but then they gradually die, and become as straight as needles; in that state they remain unaltered in size and shape, for more than fourteen months; and even after that time I found only a few floating on the surface of the water, in a state of decay; they were then much thinner than they had originally been, and were shrivelled at all their joints, the number of which could now be distinctly ascertained; the worms then assume a brownish colour, and at the least touch, or the slightest agitation of the water in which they are kept, they fall to pieces almost at every joint.

If the worms of one grain are put into water in a watch glass, they generally separate, and spread over a surface of about an inch in diameter, but during night, or if kept some hours in a dark place, they all assemble again, and entwist themselves together in a round cluster, the same as they originally formed within the cavity of the grain; the same glutinous substance by which they were cemented together whilst within the grain, surrounds and envelopes them again; and if they are suffered to get dry in that state, they retain their reviviscent property for as long a time as if they had been preserved within the grain.

The above mentioned glutinous substance appears to be of an oily nature, for if a cluster of the worms be extracted from the grains, and be slightly rubbed on the object-glass, it leaves a stain on the glass, which, if viewed through the

microscope, appears to consist entirely of a clear and colourless fluid, which neither evaporates nor dries on the glass after several months; but if the cemented mass of worms is immersed in water, the clear fluid almost instantaneously dissolves, and the worms separate.

If the worms are kept in a considerable quantity of water, and the water is frequently changed, the worms very soon die in the water, or if taken out whilst yet alive, and suffered to dry on the glass, they remain dead; but if the young worms are kept only in a moderate quantity of water in a watch-glass, the mucus, or glutinous substance, rises, and, in about twelve hours, forms a film on the surface of the water, and soon becomes nearly opaque, and sinks again upon the worms at the bottom of the glass, and in that state the worms continue alive more than two months; but if that film be carefully scummed off, the worms in the water die in less than twelve hours.

This glutinous substance must be secreted by the worms; since in grains in which the worms and the fungi or smut-balls exist, that portion of the cellular tissue of the young germens, where a worm has formed its nest and laid its eggs, is entirely preserved; whilst in those portions of the grains which are immediately in contact with the fungi, the cellular tissue entirely disappears, and the fungi are only enveloped by the external tunic of the young germen.

From these facts, we are to consider this glutinous substance as the probable cause of preserving these minute animals for such a length of time. What is recorded of the shell-snail, which can, by its own mucus, hermetically seal itself for thirty years in its shell against a wall, is similar to this: when

the mucus is dissolved, the air in the lungs is rarified, and forces its way out, so that fresh air rushes into the lungs, and it recovers.

I must however state, that this mucus continues to exist in grains of wheat now more than twenty years old, though the worms within them have, more than twelve years ago, lost their reviviscent quality; but whether length of time can, or cannot, effect such chemical change in the nature of that mucus, and by what means it has lost this preserving power, I must leave for others to decide.

Since writing these observations, I find that a great deal has been written on the subject by authors of eminence, and I have had an opportunity of reading the works of the undermentioned writers.* After an attentive perusal of their

* TURBERVIL NEEDHAM appears to have been the first discoverer of this extraordinary animal. In his "Microscopical Observations on the Worms discovered in "Smutty Corn," published in 1744, in the XLII. volume of the Philosophical Transactions; and in a small volume, under the title of "An Account of some New Microscopical Discoveries," &c. &c. published in London, 1745, he most correctly describes these worms, and their œconomy, illustrating his description by very correct figures; yet, in a subsequent publication, he most unaccountably retracts every thing he had before stated respecting them, and declares the white fibrous substance to be true zoophytes.

MAURICE ROFFREDI, in his "Memoir sur l'Origine des petits Vers ou Anguilles "du Bled Rachitique" published in the 5th volume of the Journal de Physique, 1775, has also written fully on this subject. He seems to have attentively observed the whole œconomy and peculiarities of these minute animals, in all the stages of their existence, but fell into a very great error, mistaking worms found in the stalk of a sickly young plant of wheat, for the same as those with which he had inoculated his seed grains. The worms he found, constitute a distinct disease in corn, a detailed account of which, with illustrations, is among my original drawings of all the diseases in corn, now deposited in the Banksian Library. In the same 5th volume of the Journal de Physique, page 197, ROFFREDI published a second memoir on

observations, I feel great satisfaction in finding that I have nothing to add, nor any alterations to make, in my own investigations and illustrations.

EXPLANATION OF PLATES.

PLATE I.

Fig. 1. A full grown diseased ear of white wheat, natural size.

Fig. 2. A single spiket of an unripe diseased ear in a green state; magnified 5 diameters.

Fig. 3. An infected young germen from the upper part of the green spiket; magnified 10 diameters.

Fig. 4. Transverse section of the same, with one single large worm in its cavity, but no eggs, magnified 10 diameters.

Fig. 5. An infected young germen from the lower part of the same green spiket; magnified 10 diameters.

the same subject, in which he does not offer any new facts respecting these worms, except that he successfully inoculated them upon grains of rye and barley. In the 7th volume of the Journal de Physique, published in 1776, page 369, ROFFREDI gives a third memoir on the subject, chiefly intended to clear up the confusion occasioned by many authors giving a different name to the same disease.

In the 7th volume of the Journal de Physique, published in 1776, page 43, FELIX FONTANA gives a long letter on the subject of these worms; but his chief object is, to establish two most erroneous ideas; first, he maintains that the infected grains in which the worms are found, are extraneous tumors, or gall-nuts, the mere produce of the worms; this, however, to every one who has seen one of the infected grains, must appear totally at variance with the fact. Secondly, that the suspension of the muscular motions of these worms, which is extended to such extraordinary length of time, is not a state of torpor, but real death, and extinction of life; that the worms really die as often as they get dry, and are again brought to real life, as often as they are moistened with water.

Fig. 6. Transverse section of the same, having one worm and many eggs in its cavity; magnified 10 diameters.

Fig. 7. An infected young germen in a more advanced state; magnified 10 diameters.

Fig. 8. Transverse section of the same, having several large worms, a great many eggs, and some young worms in its cavity; magnified 10 diameters.

Fig. 9. An infected and considerably distorted germen at its full size; magnified 10 diameters.

Fig. 10. Transverse section of the same, its cavity entirely filled with young worms; magnified 10 diameters.

Fig. 11. A single spiket of the ripe ear, containing four infected grains; magnified 10 diameters.

Fig. 12. One of the infected grains of the upper valves of the same spiket; magnified 10 diameters.

Fig. 13. Transverse section of the same, containing in its cavity young worms only; magnified 10 diameters.

Fig. 14. The uppermost, and smallest infected grain of the same spiket; magnified 10 diameters.

Fig. 15. Transverse section of the same; magnified 10 diameters.

Fig. 16. The lowermost and largest infected grain from the same spiket; it is nearly divided into two lobes and two cavities; magnified 10 diameters.

Fig. 17. Transverse section of the same; magnified 10 diameters.

Fig. 18. The infected grain next in order to the preceding one, on the same spiket; magnified 10 diameters.

Fig. 19. Transverse section of the same; magnified 10 diameters.

Fig. 20. An infected grain, the plant of which had been inoculated with the worms, and the uredo fœtida, or smut-balls, and both diseases had taken effect; magnified 10 diameters.

Fig. 21. Transverse section of the same; containing in its cavity some large worms, many eggs in distinct clusters, and the rest filled with uredo fœtida, or smut-balls; magnified 10 diameters.

Fig. 22. Two infected grains found in one and the same valve of an ear, the seed of which plant had likewise been inoculated with both diseases; one grain, A, is infected with the worms and the uredo, and the other with the uredo fœtida only, see B, therefore a true smut-ball; each of these grains has the two rudiments of the pistils at their summits; magnified 10 diameters.

Fig. 23. Transverse section of the same. In the cavity of the grain A, are two large worms, and many eggs in two distinct clusters, and the rest of the cavity is filled with the uredo, and the cavity of the other grain, B, is filled with the uredo fœtida only; magnified 10 diameters.

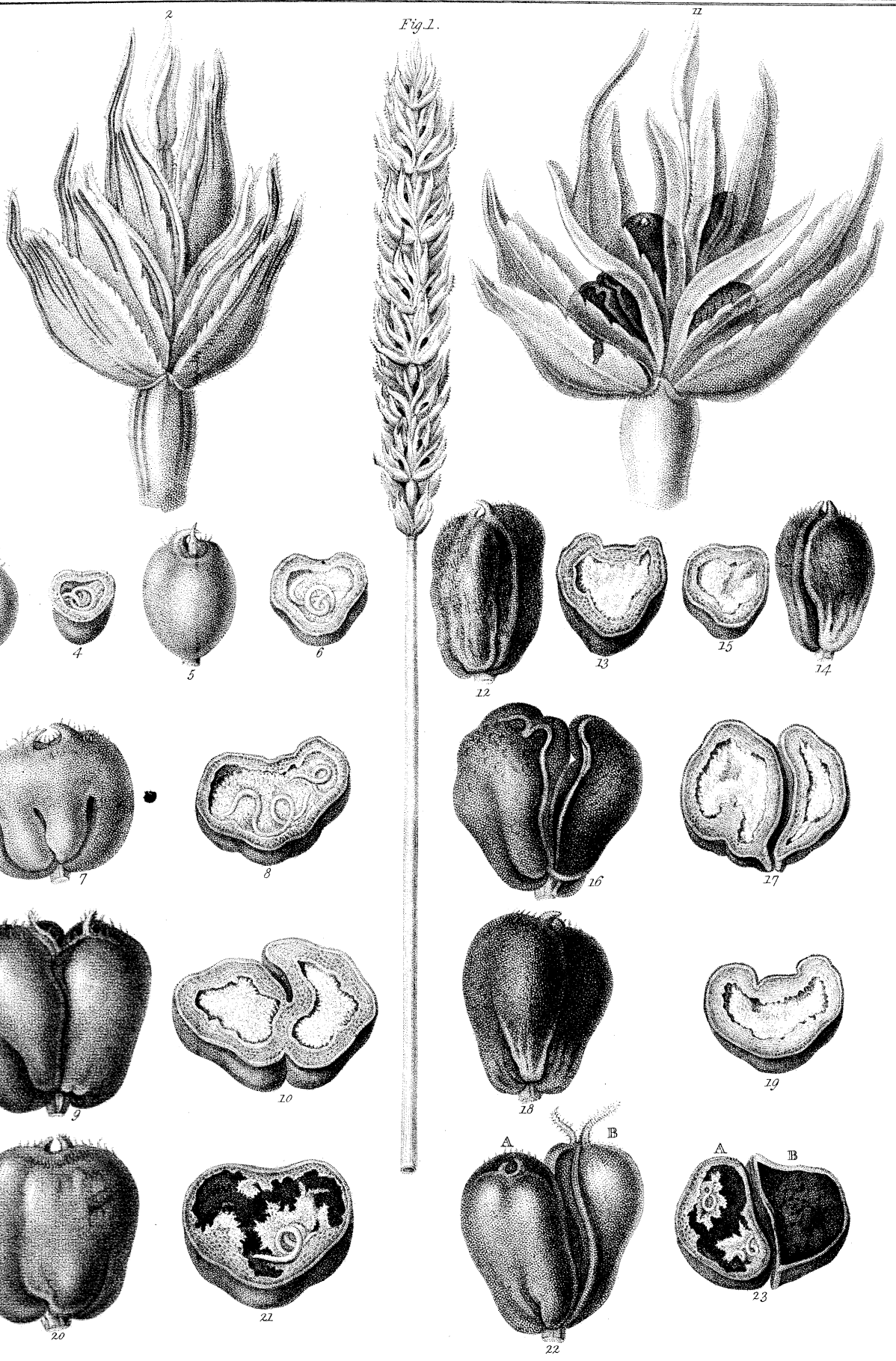
Plate II.

Fig. 1. A group of worms in water, as seen in the field of the microscope. At A, is one of the largest worms in its most usual attitude, and in the act of laying its eggs; at B, is one of the smallest old worms; at C, D, E, F, and G, is represented the manner of a young worm extricating itself from the egg; at H, is the empty egg-shell; at I, is a dead worm; the rest are worms, bending and twisting themselves

in their most usual attitudes; besides some eggs full and some empty; magnified 100 diameters.

Fig. 2. At A, is an egg containing a living young worm, twisted and rolled up in its natural manner; at B, is an egg from which the worm has recently issued; at C, is a decaying and shriveling egg; at D, D, D, are young worms; at E, is a dead worm, stretched out as is always the case; at F, is a dead worm, which had been kept 14 months in water, and only then just began to decay. All the objects of this figure are magnified 200 diameters.

Fig. 1.



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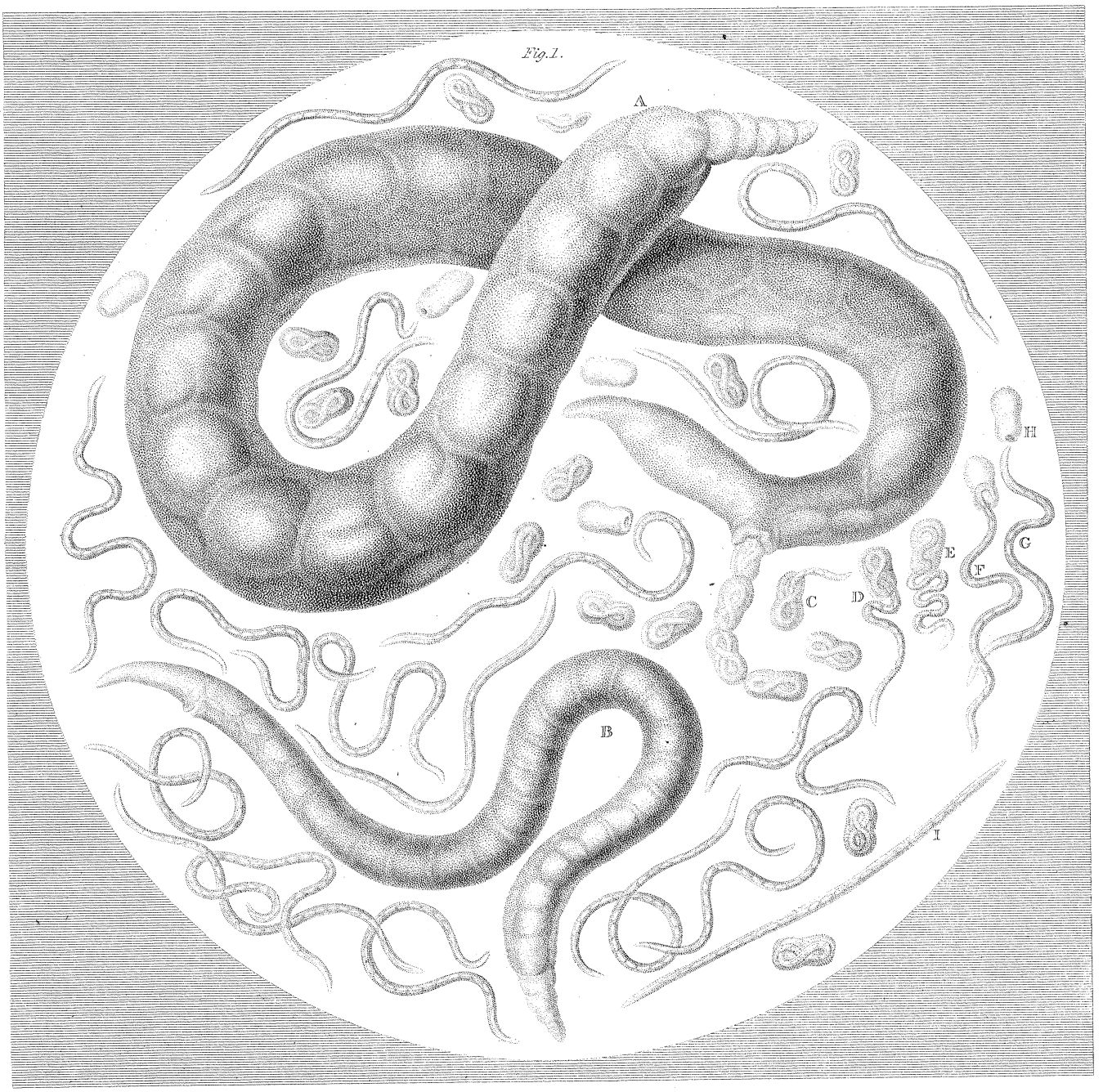
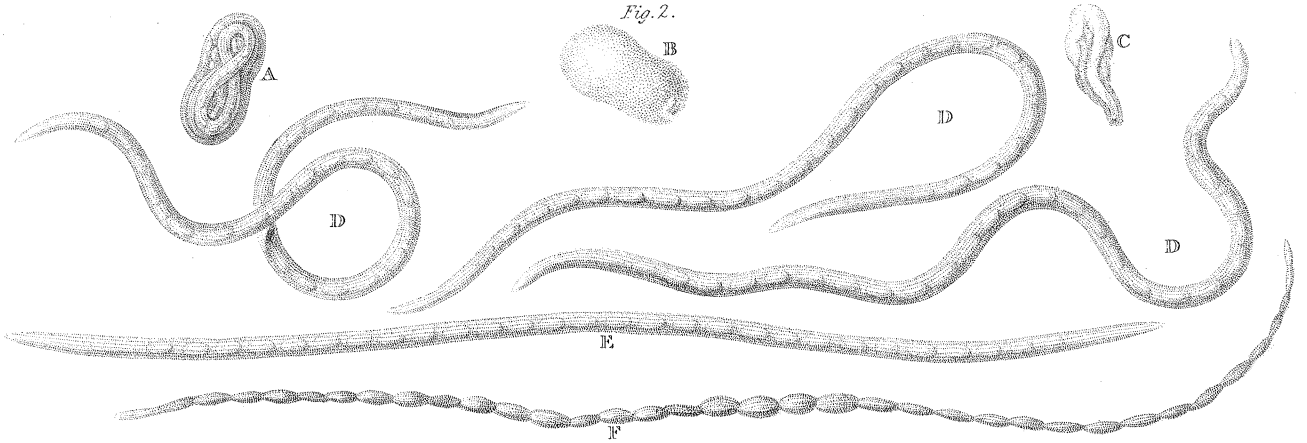


Fig. 2.



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